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Non-volatile passive matrix device and method for readout of the same

The present invention concerns a non-volatile passive matrix memory device comprising an electrically polarizable dielectric memory material exhibiting hysteresis, particularly a ferroelectric material, wherein said memory mater
5 is provided sandwiched in a layer between a first set and second set of respective parallel addressing electrodes, wherein the electrodes of the first set constitute word lines of the memory device and are provided in substantially orthogonal relationship to the electrodes of the second set, the latter constituting bit lines of the memory device, wherein a memory cell
10 with a capacitor-like structure is defined in the memory material at the crossings between word lines and bit lines, wherein the memory cells of the memory device constitute the elements of a passive matrix, wherein each memory cell can be selectively addressed for a write/read operation via a word line and bit line, wherein a write operation to a memory cell takes pla
15 by establishing a desired polarization state in the cell by means of a voltage being applied to the cell via the respective word line and bit line defining th cell, wherein said applied voltage either establishes a determined polarizati state in the memory cell or is able to switch between the polarization states thereof, and wherein a read operation takes place by applying a voltage
20 smaller than the switching or polarization voltage V_s to the memory cell and detecting at least one electrical parameter of an output current on the bit lines.

The invention also concerns the use of a non-volatile passive matrix memor device in a volumetric data storage apparatus.

25 Ferroelectric integrated circuits have revolutionary properties compared to conventional technology. Applications include non-volatile information storage devices, in particular matrix memories having advantages such as high speed, virtually unlimited endurance and high write speed; properties recently only dreamed of.

30 Ferroelectric matrix memories can be divided into two types, one type containing active elements linked to the memory cells and one type without active elements. These two types will be described below.

A ferroelectric matrix memory having memory cells in the form of

transistor comprises a thin ferroelectric film with a set of parallel conductive electrodes ("word lines") deposited on one side and an essentially orthogonal set of conducting electrodes ("bit lines") deposited on the other side, which configuration is in the following referred to as a "passive matrix memory".

the passive matrix memory, individual ferroelectric memory cells are formed at the crossing points of the opposing electrodes creating a memory matrix comprising memory cells that can be individually accessed electrically by selective excitation of the appropriate electrodes from the edge of the matrix.

Another approach for providing a matrix memory is to modify each ferroelectric memory cell by including an active element, typically an access transistor in series with the ferroelectric capacitor. The access transistor controls the access to the capacitor and blocks unwanted disturbance signals, for instance from neighbouring memory cells. The memory cell can typically include a ferroelectric capacitor and a n-channel metal-oxide-semiconductor field-effect transistor (in the following generically abbreviated "MOSFET" without indicating n-type or p-type for sake of simplicity) having its gate connected to a word line. A source/drain region of the MOSFET is connected to a bit line. One electrode of the ferroelectric capacitor is connected to the source/drain region of the MOSFET and the other electrode of the capacitor is connected to a so-called "drive line". This is the conventional concept of today and is often provided as one transistor, one capacitor (1T-1C) memory cells. Other concepts are also well-known, including two transistors or more. However, all these concepts increase the number of transistors compared to the passive matrix memory, which implies a number of drawbacks such as decreasing the number of memory cells within a given area, with increasing complexity and high current consumption. Herein, these types of devices are in the following referred to as "active" matrix memories because of the "active" element, i. e. the transistor in each memory cell.

The present invention is, however, solely directed towards passive matrix memories without active elements, such as diodes or transistors that are locally associated to the memory cell.

Read and write operations in passive matrix memories may be performed by means of a so-called "partial word addressing", whereby only a portion, typically one of the memory cells on a given word line are read or written. To accomplish such a partial read or write operation the non-addressed cells are

non-activated word lines or bit lines are voltage-biased according to a so-called "pulsing protocol" in order to avoid partial switching of the non-addressed cells. The choice of pulsing protocol depends on a number of factors, and different schemes have been proposed in the literature for applications involving ferroelectric memory materials exhibiting hysteresis. This is described for instance in the present applicant's co-pending Norwegian patent application No. 20003508 filed 7 July 2000. This application describes a protocol for a passive matrix memory. On the other hand, normally the biasing of the non-addressed cells causes disturb voltage which can result in loss of memory content or give rise to leakage currents and other parasitic currents, here called "sneak currents", which can mask the current of an addressed memory cell during a read operation and thereby mask the data content during the read. Depending on the type of device in question, different criteria for avoiding or at least reducing disturbance of non-addressed memory cells can be defined, such as methods for sneak current cancellation. Another way is to lower the sensitivity of each cell in the matrix to small-signal disturbances, which can be achieved by cells that exhibit a non-linear voltage-current response, involving e.g. thresholding, rectification and/or various forms of hysteresis.

In order to improve the performance of both active and passive ferroelectric memory devices, the memory matrix can be internally divided, "segmented" into smaller blocks, so-called "segments", for instance to reduce power requirements. Normally this segmentation is transparent to a user. Another reason for segmentation is the problem with ferroelectric capacitors that they suffer from a so-called "fatigue", which means that after a ferroelectric capacitor has been switched a large number of times, say several millions, it cannot hold a remanent polarization and hence stops functioning. A solution to this particular problem can be smaller matrix segments to avoid switching an entire row of capacitors. This is disclosed for instance in US-A-5 567 633.

Another document describing a segmented memory matrix is Gary F. Derbenwick & al., "Non-volatile Ferroelectric Memory for Space Applications", Celis Semiconductor Corporation, Colorado Springs. This document describes a segmented memory matrix able to reduce power requirements in an active matrix using a one transistor, one capacitor memory cell architecture (1T, 1C).

Examples of passive matrix memories employing ferroelectric memory material can be found in the literature dating back 40-50 years. For instance W.J. Merz and J.R. Anderson described a barium titanate based memory in 1955 (W.J. Merz and J.R. Anderson, "Ferroelectric storage devices", Bell. Lab. Record. 1, pp. 335-342 (1955)), and similar work was also reported by others promptly thereafter (see, e.g. C.F. Pulvari "Ferroelectrics and their memory applications", IRE Transactions CP-3, pp. 3-11 (1956), and D.S. Campbell, "Barium titanate and its use as a memory store", J. Brit. IRE 17 (7), pp. 385-395 (1957)). Another example of a passive matrix memory can be found in IBM Technical Disclosure Bulletin, Vol. 37, No. 11, November 1994. However, none of these documents describe a solution to the problem with disturbed non-addressed cells.

Another approach to remedy the problem would be to modify the ferroelectric material in order to create a square-like hysteresis loop. However, also this has not yet been described in more detail.

Accordingly, there is a need of a passive matrix memory without the above negative attributes, such as disturbed non-addressed cells.

In the light of the above, it is an object of the invention to provide a passive matrix memory device which solves the problem with disturbed non-addressed memory cells. Another object of the invention is to provide a passive matrix memory device which minimizes the influence of cumulative signals from non-addressed cells during reading of stored data. Finally it is also an object of the invention to provide a readout method in a passive matrix memory device and compatible with the above-mentioned objects.

The above objects as well as further advantages and features are realized with a non-volatile passive memory matrix device according to the invention which is characterized in that the word lines are divided into a number of segments, each segment comprising and being defined by a plurality of adjoining bit lines in the matrix, and that means are provided for connecting each bit line assigned to a segment with an associated sensing means, thus enabling simultaneous connection of all memory cells assigned to a word line on a segment for readout via the corresponding bit lines of the segment, each sensing means being adapted for sensing the charge flow in the bit line connected therewith in order to determine a logical value stored in the

In a first advantageous embodiment of the memory device according to the invention the means for simultaneous connection of each bit line of a segment with associated sensing means during addressing are multiplexers. In that case the number of multiplexers may correspond to the largest number of bit lines defining a segment, each bit line of a segment being connected with a specific multiplexer. It is then preferred that the output of each multiplexer is connected with a single sensing means, and particularly the single sensing means can then be a sense amplifier.

In a second advantageous embodiment of the memory device according to the invention the means for simultaneous connection of each bit line of a segment to an associated sensing means during addressing is a gate means. In that case all the bit lines of a segment can be connected with a specific gate means, each gate means having a number of outputs corresponding to the number of bit lines in the respective segment, and each output of each gate means is connected with a specific bus line of an output data bus, the number of bus lines thus corresponding to the largest number of bit lines in a segment, and each bus line being connected with a single sensing means.

Preferably the gate means then comprises pass gates and preferably the sensing means is a sense amplifier.

The above objects and other advantages and features are also realized with the readout method for a memory device according to the invention, whereby the method is characterized by dividing the word lines into a number of segments, each segment comprising and being defined by a number of adjacent bit lines in the matrix, connecting each bit line within a word line segment with an associated sensing means, activating according to the protocol one word line of a segment at a time by setting the potential of said one word line of the segment to the switching voltage V_s during at least a portion of the read cycle, while keeping all bit lines of the segment at zero potential, and determining the logical value stored in the individual memory cells sensed by the sensing means during the read cycle.

In an advantageous embodiment of the readout method according to the invention, all word lines and bit lines when no memory cell is read or written, are kept at a quiescent voltage of approximately $\frac{1}{2}$ of the switching

setting the potential of said one word line of the segment to the switching voltage V_s during at least a portion of the read cycle, while all bit lines of the segment are kept at zero potential, and the logical value stored in the individual memory cells sensed by the sensing means during the read cycle determined.

Finally, the above objects and other features and advantages are also achieved according to the invention with the use of the inventive non-volatile passive memory device and the inventive method for readout in a volumetric data storage apparatus with a plurality of stacked layers, each layer comprising one of the non-volatile passive matrix memory devices.

The invention shall now be more fully described on the basis of discussions of its general background and preferred embodiments presented hereinafter when read in conjunction with the appended drawing figures, wherein

fig.1 shows a principle drawing of a hysteresis curve for a ferroelectric memory material;

fig. 2 a schematic diagram of a portion of a passive memory matrix with crossing electrode lines and wherein the memory cells comprise a ferroelectric material localized between these electrodes where they overlap

fig. 3 an enlarged cross-sectional view taken along line A-A in fig. 2;

fig. 4 a functional block diagram illustrating full word read in a ferroelectric matrix memory;

fig. 5 a functional block diagram illustrating a passive matrix memory according to a preferred embodiment of the invention and with segmented word lines;

fig. 6 a functional block diagram illustrating a passive matrix memory according to a preferred embodiment of the invention and with segmented word lines;

fig. 7a a simple full word read timing diagram with a following write/refresh cycle provided for addressing a word line of a segment of the memory matrix in "full word read";

fig. 7b a variant of the timing diagram in fig. 7a: and

fig. 8 the same embodiment as in fig. 5, but with electrical segmentation of the word lines,

fig. 9 the embodiment as in fig. 6, but with electrical segmentation of the word lines, and

- 5 fig. 10 schematically how the memory matrix in fig. 5 or 6 can be implemented in a volumetric memory device.

Before giving a detailed description of preferred embodiments, the general background of the present invention shall be discussed in order to give a better understanding of how a passive matrix memory, or even a single
 10 memory cell in such a memory works. In this connection reference is made to fig. 1, which shows a typical so-called "hysteresis loop" of a ferroelectric material, whereas the polarization P of the ferroelectric material is plotted versus the electric field E . The value of the polarization will travel around the loop in the direction indicated. A ferroelectric material with a hysteresis
 15 loop as shown in fig. 1 will change its net polarization direction ("switching" upon application of an electric field E that exceeds a so-called coercive electric field E_c . As the electric field E exceeds the coercive electric field E the polarization P changes abruptly to a large positive value $+P_r$ (assuming starting at negative polarization at zero electric field). This positive
 20 polarization $+P_r$ remains until a large negative electric field exceeding a negative coercive electric field $-E_c$ changes the polarization again back to negative polarization. In this way, memory devices provided with capacitor comprising ferroelectric material will exhibit a memory effect in the absence of an applied external electric field, making it possible to store non-volatile data by applying a potential difference across the ferroelectric material,
 25 which evokes a polarization response. The direction (and magnitude) thereof may thus be set and left in a desired state. Likewise, the polarization status can be determined. Storing and determining data will be described in more detail below.

- 30 Depending on the required switching speed etc., a nominal voltage V_s employed for driving the polarization state of the ferroelectric material is typically selected considerably larger than the coercive voltage E_c . The nominal voltage V_s is generically illustrated with a dashed line in fig. 1, but is by no means limited to this particular value. Other values can be

Fig. 2 illustrates a portion of a m-n memory matrix 11 of a passive matrix memory 10 showing two mutually opposing sets of parallel electrodes, viz. word line electrodes WL and bit line electrodes BL. The word line and the bit line electrodes WL;BL are arranged perpendicular to each other, whereby they at the intersecting areas define side walls of specific volume elements of an insulating ferroelectric material (described in more detail below) and which in its turn define the volume of capacitor-like memory cells in the memory matrix 11. Fig. 3 discloses a cross-sectional view along line A-A in fig. 2. The dielectric of each "capacitor" is the ferroelectric material in a ferroelectric layer 12, where the thickness of the material defines the height of the volume elements which in their turn define the memory cells 13. — For reasons of simplicity, only three crossing points between the word line and bit line electrodes WL;BL are illustrated in fig. 2.

By application of a potential difference V_s between two opposing electrodes: the word line WL and the bit line BL in a cell 13, the ferroelectric material in the cell 13 is subjected to an electric field E which evokes a polarization response, having a direction which may be set and left in one of two stable states, positive or negative polarization, according to what is disclosed for instance in fig. 1. The two states represent the binary states "1" and "0". Likewise, the polarization status of the cell 13 may be altered or deduced by renewed application of a potential difference between the two opposing electrodes WL and BL addressing that cell 13, which either causes the polarization to remain unchanged after removal of the potential difference, to flip to the opposite direction. In the former case, a small current will flow in response to the applied voltage, while in the latter case the polarization change causes a large current. The current is compared to a reference which can be provided in a number of ways (not shown) to be able to decide whether a "0" or a "1" is present. If the read is a destructive read, the polarization state in some of the cells will be switched to the opposite state. For instance can the polarization state of the cell be switched to "0" whether it is the state "1" or the state "0" that is read. The initial state must be written back to a cell in the memory to keep the information in the memory, i.e. the readout value. A more detailed description of how a passive matrix memory operates will be given in below when describing a preferred embodiment of the invention.

Also in order to improve the understanding of the present invention, reference can be made to fig. 4 illustrating another readout method for passive matrix memories, hereinafter called "full word read", whereby an active word line, herein the first word line WL_1 comprising a desired mem-
 5 cell 13, is sensed over its entire word length, that is, each of the memory cells 13 defined by the bit lines BL_1, \dots, BL_n . Full word read per se is a known concept described for instance in US-A-6 157 578. In said document, however, the solution is directed to an active matrix memory device, with the purpose of increasing the speed of transferring data stored in a relatively
 10 large block of a memory matrix. The present invention is on the contrary related to passive matrix memories, whereby prior art knowledge regarding active matrices, such as described in US-A-6 157 578, is not relevant since active devices does not have the problem with disturbing non-addressed cells.

15 It is important to notice that according to the pulsing protocol for full word read in a passive matrix memory, unused word lines, in this case to the word lines WL_2, \dots, WL_m can be maintained at the same potential or essentially the same potential as the bit lines BL_1, \dots, BL_n . Consequently, there is no disturbing signal on any of the non-addressed cells of the memory matrix 10. For readout of
 20 data (sensing), the active word line, in this case the first word line WL_1 , is brought to a potential causing current I to flow through the cells on the crossing bit lines BL_1, \dots, BL_n . The magnitude of the current I depends on the polarization state each cell 13 and are determined by sensing means 26, one for each bit line BL as shown in fig. 4. The sensing means can for instance
 25 sense amplifiers.

The full word read method offers several advantages. For instance may the read voltage be chosen much higher than the coercive voltage without incurring partial switching in non-addressed cells, and the method is compatible with a large matrix.

30 The preferred embodiments of the present invention are illustrated in figs. 5-7 of the drawings. An accompanying timing diagram that accomplishes zero volt disturb of non-addressed memory cells, while applying switching voltage V_s on all cells of the active word line WL_1 during reading of all cells in an active segment. A preferred timing diagram is shown in fig. 7a and an
 35 alternative timing diagram is disclosed in fig. 7b

With reference to fig. 5 which shows a preferred embodiment of the passive matrix memory according to the present invention, the matrix proper is embodied as an $m \cdot n$ matrix formed by m word lines $WL_{1,...,m}$ and n bit lines $BL_{1,...,n}$. The word lines are divided in q segments S , each segment S being defined by a number k adjacent bit lines BL in the matrix BL . Preferably k the same for each segments, such that $q \cdot k = n$. For readout the first bit line each segment S can now be coupled by a first multiplexer 25_1 to a first sensing means 26_1 . The second bit line in each segment shall corresponding be coupled to another multiplexer 25_2 , such that k 'th line in each segment will be coupled to last multiplexer 25_k . The number of multiplexers (MUX) 25 shall in other words shall be equal to the largest number of bit lines BL which defines a segment. It is, of course, nothing that prevents that the number of bit lines in each segment S can be different, but if the memory cells on the bit lines on the segment contain data words with the same length k will be the same for all segments. Each multiplexer 25 is connected with sensing means 26 for readout of data and the number of sensing means 26 will hence also be equal to the largest number k bit lines BL which defines segment. Different from conventional passive matrix memories which use partial word read, all the memory cells 13 in a word line segment n is connected simultaneously to the sensing means 26 such that all bit spots on word line segment can be read out in parallel. Specifically can the sensing means be sense amplifiers. – For simplicity are only the two first segments S_1 , S_2 and the last segment S_q rendered in fig. 5 and the same applies to the associated multiplexers 25 and sense amplifiers 26. – Data which are stored and/or shall be stored in the memory matrix 11 can be accessed by means of an associated row decoder and column decoder which is not shown in fig. 5 and the data which is stored in the memory cells 13 in the memory matrix 1 can be read out with a pulse protocol, e.g. as discussed in connection with fig. 7a via the sense amplifiers 26 which are connected to the bit lines over the multiplexers 25. All bit lines BL which define a word line segment S are routed to multiplexers 25 and are selected only when a given word line WL in this segment is active. In this manner all bit lines in the active word line WL in the segment S is read out in parallel in a “full word configuration” as all bit lines are distributed among the sense amplifiers 26.

In a practical embodiment the passive memory device can for instance be a 16 Mbit memory divided into 8 segments S with $k = 2$ and $q = 8$.

256 000 word lines WL of each 64 bits. It will then be 8 bit lines BL in each segment S, in other words $k = 8$. Other architectures are of course, also possible, e.g. with 9, 16 or 32 bit lines in each segment S.

5 In another preferred embodiment of the invention at least 256 memory cells 13 are used in each segment S. With the use of a 32:1 multiplexers 25 this forms 8192 bits wide memory with only 32 duplication of word line drivers. Each word line will, of course, be segmented according to the number of provided sense amplifiers 26.

10 In fig. 6 there is shown an alternative embodiment of the memory device according to the present invention, wherein the multiplexers are replaced by gate means 25. The gate means 25 activate the bit lines BL in the same manner as the multiplexers.

15 Preferably, the gate means 25 are realized as pass gates connected with each bit line BL in a segment S. While the number of multiplexers 25 in the embodiment in fig. 5 shall be equal to the number of bit lines BL in the segment S, namely k , the number of pass gates 25 in the embodiment in fig. 20 shall correspond to the number q of segments S. The number of outputs on each pass gate 25 corresponds to the number of bit lines BL in the respective segment S. In order to maintain parallel readout of memory cells 13 of the active word line WL in the segment S, a sense amplifier 26 is used for each bit line BL in the segment, each sense amplifier 26 being connected to one of the lines 27 on a data bus 28. A first output of the pass gate is connected to the first bus line 27_1 and the second to the second bus line 27_2 etc. and the number of bus lines 27 and sense amplifiers will, of course, be the greatest 25 number of bit lines BL which defines a segment S.

Figs. 7a and 7b render alternative timing diagrams for a full word read cycle

30 Fig. 7a shows a timing diagram for full word read with a following write/read cycle ("refresh", "write back") for a word line segment. This timing diagram is based on a four-level voltage protocol. According to this timing diagram all word lines and all bit lines are, when no cell in the matrix is read or written, kept at a quiescent voltage equal to zero volts. All memory cells have an address which represent the crossings formed of an activated word line WL and by all bit lines BL within this segment which is to be read.

The inactive word lines WL and all bit lines BL follow the same potential curves during the read cycle. During the read cycle the word line contacting the cells to be read is set to switching voltage V_s . At the same time interval all bit lines are kept at zero voltage. In the timing diagram shown there is provided that application of the switching voltage V_s on the word line side of a cell and a zero voltage on the bit line side of the same cell implies that a "0" is written into the cell. According to this, in both timing diagrams show all cells on the active word lines are set to the zero state after the read operation has been performed. Therefore, in order to restore data stored in the memory, it will be necessary to write back "1" only on the bit lines which has cells that should contain "1". This is shown in both examples in figures 7a and 7b, where a voltage with reversed polarity is applied to the cell which shall be written with "1" during the read cycle as indicated in the diagram.

Fig. 7b illustrates an alternate timing diagram based on a four-level voltage protocol. According to this embodiment all word lines and bit lines, when a cell in the matrix is read or written, are kept at a quiescent voltage $V_s/3$.

The exact values for all timing points illustrated as examples in figures 7a and 7b are dependent on the materials of the memory cells and the details of the design.

In the embodiments of fig. 5 and 6 the word lines could in principle be uninterrupted, i.e. that they are extending continuously to the separate segments, the segments only being defined by the bit lines in question. Multiplexing and protocols for read and write must then be adapted thereto. It is, however, no advantage that the word lines become too long. With a limited number of segments and a limited number of bit lines in each segment this is avoided, e.g. as in the above mentioned example, where 256 000 word lines and 8 segments with 8 bit lines in each segment are used. The memory then obtains as stated a storage capacity of 16 Mbits. There are, however, also other disadvantages with continuous word lines. If the bit spots of the memory cells in the segment S read with high voltage on the active word line, the same high voltage will be impressed on the active word line in all segments and even though only the bit lines in the addressed segments are connected, capacitive couplings and sneak currents can be formed and influence e.g. the memory cells in adjacent non-active word lines in the segment, something which may lead to erroneous readings or noise

contributions. In a practical embodiment of the memory device according to the invention it will hence be relevant also to be able to segment the word lines electrically such that only the active word line within the addressed segment is connected electrically to the driver, while the corresponding word line segments in the remaining segments are disconnected. This will particularly be relevant when the protocol in fig. 7 is used and can take place with an embodiment of the memory device as shown in fig. 8, which in principle corresponds to that in fig. 5. A not shown driver in a driver group 20 is selected by means of a segment selector 22 which e.g. may be realized as a selector bus, such that the word line WL in the selected segment S is activated for a read or write cycle. The multiplexers 25 which are controlled by the segment selector means 22 can be connected with a selected driver in the group 20 via switches 24 and controlled via the selector means 22 over switchable cache memory 21. The specific multiplexer 25 is simultaneously addressed for connecting the bit lines BL in the addressed segment to the sense amplifier 26. In purely practical terms each word line WL in a segment can be connected to an AND gate, e.g. a CMOS logic gate or a pass gate, at the segment be addressed from a word line or address decoder. For instance the word line WL_1 is selected in the segment S_1 and it is then voltage only on this bit line within the segment S_1 . With destructive readout now all memory cells and the word lines WL_1 in the segment S_1 will be switched to zero state while the multiplexer 25 connects all bit lines in the segment S_1 to the respective sense amplifiers $26_1...26_k$. All cells on the activated word line can hence be read out, i.e. a full word read is obtained if the word line of the segment is defined to contain a data word. While the state of all cells on the selected word line WL_1 then is detected, the remaining word lines $WL_2...WL_m$ and bit lines BL_1-BL_k is kept on a quiescent voltage near the biasing points of the sense amplifiers 26 and in principle there will then be no disturbance contribution from the remaining cells of the segment. Neither will there be any bias voltage on the cells on the bit line, such that disturbing signals to the input of the sense amplifiers 26 can be generated. The data output of the sense amplifier 26 is conveyed to a two-way data bus 23 while write logic 29 is connected in parallel on the output of the multiplexers for writing of data to the bit spots of the cells on an active word line in the segment, the word lines in the segments being selected in corresponding ways via the selector means 22 as in case of readout. Preferably there are

22 and the latter connect drivers and multiplexers 25 via a number of line switches 24 controlled by the selector means 22.

Fig. 9 shows an embodiment functionally equivalent to that of fig. 8, but which additionally corresponds to the embodiment in fig. 6 wherein the multiplexers have been replaced by pass means 25. Each pass means 25 can e.g. comprise switching transistors 25a which function as pass gates, one for each line such that there will be a total of k switching transistors 25a in a pass means 25. As is the case with the embodiment in fig. 8, driver groups are provided, one for each segment, while the selector means 22 now is replaced by a driver group selector 22a. The addressing of the separate word line WL takes place over the output in a word line address bus 30 under control by the group selector 22a. In readout the bit lines 25a are connected to the bus line 27 in the data bus 28 and the data output of the sense amplifier is connected with a two-way data bus 23. Correspondingly as in fig. 8 the write logic 29 is provided in parallel over the sense amplifiers 26 and when writing takes place, the word line segment is selected via the group selector 22a and with addressing over the word line address bus 30.

Basically the necessary devices and means for selection, decoding and addressing, like not shown timing logic, are well-known in the art and commonly employed in the matrix-addressable memories whether they are active or passive and hence shall not be discussed in further detail here.

The number of voltage levels and the voltage levels themselves in the pulse protocol can be selected arbitrarily as long as the requirements for performing full word read are met. Further, the polarity of the voltages according to the protocols shown may as well be reversed.

In a practical circuit technology for the realization of the memory device according to the present invention, the memory matrix can be provided on a substrate and word line drivers integrated therein, such that the total area of the device does not increase.

The segmented word lines could as well be implemented on stacked memory planes, with the bit lines BL connected vertically to the multiplexers or gate means 25. This is illustrated in fig. 10, which shows schematically and in cross section an embodiment wherein memory devices 10 according to the

data storage apparatus wherein each layer or memory plane P comprises one memory device 10. By providing the memory devices in a staggered arrangement, the respective word lines and bit lines can be connected over so-called staggered vias, i.e. alternating horizontal and vertical

5 “over-the-edge” connections with driver and control circuitry in the substrate 14. The substrate 14 can be inorganic, i.e. silicon-based, and hence the circuitry may be implemented in e.g. a compatible CMOS technology. Figure 8 shows only two memory planes P_1, P_2 (note that only a limited number of lines are shown), but in practice the volumetric data storage apparatus may

10 comprise a very large number of memory planes, from 8 and well beyond 10 or more, realizing a memory with very high capacity and storage density, as each memory plane only will be about $1\mu\text{m}$ thick or even less.

Advantages of the passive matrix memory device described above include simplicity of manufacture and high density of cells. Further advantages are:

- 15 a) If the word lines are segmented electrically, non-addressed memory cells will during the read cycle be subjected to zero volt potential (or a small potential), given that the protocol according to fig. 7a is used. This will reduce the number of disturb signals that could result in loss of memory content as well as eliminate all disturbs during a read operation that give rise to sneak currents.
- 20 b) The data transfer rate will be at the maximum rate as allowed by the number of bit lines within a segment.
- c) The readout voltage V_s may be chosen much higher than the coercive voltage without incurring partial switching in non-addressed cells. This
- 25 allows for switching speeds approaching the highest possible speed of polarizable material in the cells.
- d) The readout method is compatible with large matrices.

In addition the memory device of the invention can be realized with a reduced number of sense amplifiers, which is an advantage when the memory is large and also with regard to the power consumption of the sense amplifiers. This can be high, but may also be reduced to some extent by appropriate power management of the driving and addressing circuitry. Moreover, a reduction in the number of sense amplifiers implies that real

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optimization in the memory device. Finally, the segmentation of the word lines implies that errors during readout or addressing will be located in a single word in the event of a single word line fault.